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MAIL STOP PATENT
Attorney Docket No. 25865

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re Application of: Group Art Unit: 3752

KHAIN et al.

Serial No.: 10/726,563

Filed: December 4, 2003

Title: **METHOD AND APPARATUS FOR CONTROLLING ATMOSPHERIC CONDITIONS**

TRANSMITTAL LETTER

Commissioner of Patents
P.O. Box 1450
Alexandria, Va 22313-1450

Sir:

Submitted herewith for filing in the U.S. Patent and Trademark Office is the following:
(1) Transmittal Letter;
(2) Request for Priority;
(3) Priority Document No. IL147287.

The Commissioner is hereby authorized to charge any deficiency or credit any excess to Deposit Account No. 14-0112.

Respectfully submitted,

NATH & ASSOCIATES PLLC

By: Gary M. Nath

Gary M. Nath
Registration No. 26,965
Marvin C. Berkowitz
Reg. No. 47,421
Customer No. 20529

Date: May 19, 2004
NATH & ASSOCIATES PLLC
1030 15th Street NW - 6th Floor
Washington, D.C. 20005
GMN/MCB/ng/Priority_Tran

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REQUEST FOR PRIORITY UNDER 35 U.S.C. §119

Commissioner for Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Sir:

In the matter of the above-captioned application, notice is hereby given that the Applicant claims as priority date DECEMBER 25, 2001, the filing date of the corresponding application filed in ISRAEL, bearing Application Number IL147287.

A Certified Copy of the corresponding application is submitted herewith.

Respectfully submitted,
NATH & ASSOCIATES PLLC

Date: May 19, 2004

By: Gary M. Nath
Gary M. Nath
Reg. No. 26,965
Marvin C. Berkowitz
Reg. No. 47,421
Customer No. 20529

NATH & ASSOCIATES PLLC
6TH Floor
1030 15th Street, N.W.
Washington, D.C. 20005
(202)-775-8383
GMN/MCB/ng (Priority)

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זאת לתעודה כי רצופים בזה העתקים נכונים של המסמכים שהופקדו לכתחילה עם הבקשה לפטנט לפי הפרטים הרשומים בעמוד הראשון של הנספח.

This 06-05-2004 היום

רשם הפטנטים
Commissioner of Patents

נתאשר
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חוק הפטנטים, תשכ"ז – 1967
PATENTS LAW, 5727-1967

בקשה לפטנט
Application For Patent

לשימוש הלשכה For Office Use	
מספר: Number	147287
תאריך: Date	
הוקדם/נדחה: Ante/Post-dated	25-12-2001

אני, (שם המבקש, מענו ולגבי גוף מאוגדת מקום התאגדותו)
I, (Name and address of applicant, and in case of body corporate-place of incorporation)

יישום חברה לפיתוח המחקר של האוניברסיטה העברית בירושלים, חברה ישראלית מרחוב ז'בוטינסקי 46, ירושלים 92182, ישראל

Yissum Research Development Company of the Hebrew University of Jerusalem, Israeli Company of 46 Jabotinsky Street, Jerusalem 92182, ISRAEL

The Inventors: FELDMAN Yuri, KHAIN Alexander, PUZENKO Alexander, PINSKY Mark, RYABOV Yaroslav, ARTCHIPOV Vladimir

הממציאים: פלדמן יורי, קיין אלכסנדר, פוזנקו אלכסנדר, פינסקי מרק, ריאבוב ירוסלב, ארצ'יפוב ולדימיר

בעל אמצאה מכח הדין ששמה הוא
Owner, by virtue of Right of Law of an invention the title of which is

(בעברית) (Hebrew)

שיטה ומכשיר לשליטה בתנאי אטמוספירה

(באנגלית) (English)

Method and apparatus for controlling atmospheric conditions

Hereby apply for a patent to be granted to me in respect thereof.
מבקש בזאת כי ינתן לי עליה פטנט

* בקשת חלוקה Application of Division	* בקשת פטנט מוסף Appl. for Patent of Addition	דרישת דין קדימה* Priority Claim		
מבקשת פטנט from application	* לבקשה/לפטנט to Patent/Appl.	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
No. ____ מס'	No. ____ מס'			
Dated מיום	Dated מיום			
P.o.A.: General כללי * יפוי כח:	filed in case **P114692** הוגש בעניין			
המען למסירת מסמכים בישראל Address for Service in Israel **C. 134617**				
REINHOLD COHN AND PARTNERS Patent Attorneys P.O.B. 4060, Tel-Aviv	ריינהולד כהן ושותפיו עורכי פטנטים ת"ד 4060, תל-אביב			

חתימת המבקש
Signature of Applicant
בשם המבקשים,
ריינהולד כהן ושותפיו
ע"י: קוהן

היום 24 בחודש December שנת 2001
This 24 of December Year 2001

לשימוש הלשכה
For Office Use

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This form, impressed with the Seal of the Patent Office and indicating the number and date of filing, certifies the filing of the application the particulars of which are set out above.

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Delete whatever is inapplicable

שיטה ומכשיר לשליטה בתנאי אטמוספירה

Method and apparatus for controlling atmospheric conditions

Yissum Research Development Company of the Hebrew University of Jerusalem

יישום חברה לפיתוח המחקר של האוניברסיטה העברית בירושלים

The Inventors:
FELDMAN Yuri
KHAIN Alexander
PUZENKO Alexander
PINSKY Mark
RYABOV Yaroslav
ARTCHIPOV Vladimir

הממציאים:
פלדמן יורי
קיין אלכסנדר
פוזנקו אלכסנדר
פינסקי מרק
ריאבוב ירוסלב
ארצ'יפוב ולדימיר

C. 134617

Method and apparatus for controlling atmospheric conditions

FIELD OF THE INVENTION

This invention relates to a method and apparatus for weather control and modification, and in particular, for controlling atmospheric conditions by seeding dispersing materials in the atmosphere causing the precipitation of water therein.

BACKGROUND OF THE INVENTION

Various techniques are known in the art for treating atmospheric conditions to precipitate atmospheric water. Such techniques are utilized for the regulation and enhancement of rain, prevention and suppression of hail, dispersal of ground mist and abatement of fog. In particular, the regulation and enhancement of rain is especially important in countries that experience water shortage for agriculture and other human activities, for example, while the modifying of unfavorable weather by precipitation of fog or mist is crucial for increasing visibility, for example, on roads and runways of airports.

It is known that typically water droplets in clouds and fogs are relatively small, having typical droplet radii for clouds and fogs, respectively of 1-10 microns and 1-5 microns. However, in order to trigger raindrop formation, the droplet radius should exceed 20-25 microns (see, for example, Khain *et al*, "Notes on the state-of-the-art numerical modeling of cloud microphysics". *Atmos. Res.,* 2000, V. 55, P. 159-224). Droplets having a radius of 1 to 100 microns will be referred to hereafter as microscopic droplets, and droplets having a radius exceeding 25 microns will be referred to hereinafter as drops. All references to the size of drops or droplets refer to their radius.

Water drops with a radius of higher than 25 microns have sufficient mass to attain a fall velocity under the force of gravity sufficient to collect smaller

droplets and precipitate from clouds or fog owing to their collisions and coalescence. On the other hand, the gravity-induced approach of small droplets does not usually lead to their coalescence, because most of the small droplets move around their counterparts together with the airflow.

Fig. 1 illustrates a scheme of collisions of small droplets **11** having a radius of r with a large drop **12** (also known as a "drop-collector") having a radius of R. The drop **12** moving under the force of gravity may collect the small droplets locating within a cylinder **13**. A volume of the cylinder **13** over a unit of time reads:

$$V = \pi(R+r)^2 \, [V_R - V_r], \qquad (1)$$

wherein $\pi(R+r)^2$ is the area of a geometric cross-section **14**; and V_r and V_R are the velocities of the droplets **11** and the drop-collector **12**, respectively.

A collision rate N (the number of collisions per a unit of time) may be expressed as a product of the volume of the cylinder **13** and the concentration C of the droplets **11**, to wit:

$$N = V\,C \qquad (2)$$

However, the number of collisions in clouds and fogs is, in fact, much smaller than that determined by Eq. (2), because most of the small droplets move around the drop-collector **12** together with the airflow without collisions. Collisions between the droplets are possible only due to droplet inertia that leads to a deviation of the collected droplets from streamlines **16** of the airflow. Since the inertia of small droplets is small, most of the droplets move around the drop-collector **12**, avoiding collisions. Thus, only the droplets located in a swept volume **15** (that is a rather small fraction of the volume of the cylinder **13**) experiences collisions. This fraction is referred to as a *collision efficiency* that can be defined as the ratio between an area S of the collision cross-section **17** and the area of the geometrical cross-section **14**, to wit:

$$E = S \,/\, \pi(R+r)^2 \qquad (3)$$

As a result, an effective collision rate N_{eff} can be determined according to the following equation:

$$N_{eff} = EVC \qquad (4)$$

Fig. 2 shows a dependence of the collision efficiency E on the ratio r/R plotted for various radii R of the drop-collector (**12** in Fig. 1). It can be appreciated that when the drop collectors have a small radius, i.e. around 10 microns (curve **21**), the value of the collision efficiency is very small (ranging from 10^{-4} to 10^{-2}). In other words, the small droplets, in fact, do not collide over a reasonable period of time.

On the other hand, when the drop-collectors reach a radius exceeding about 20 microns, the collision efficiency E has a value sufficient to produce collisions, i.e. larger than 0.1 (curves **22-24**). This drop-collector size is usually thought of as the minimum drop size necessary for triggering a process of collisions and creating the raindrops, i.e., drops larger than about 100 microns in radius.

Therefore, if a cloud does not have a sufficient number of large drop-collectors, it cannot realize fully its precipitation potential. Such a situation in clouds is quite usual, because the time necessary to form large drops in natural conditions often exceeds the time period of the cloud's development.

Various techniques have been used to date to generate drop-collectors having a size sufficient for the coalescence of cloud and fog droplets. One of the methods of treatment of atmospheric conditions for this purpose is the *glaciogenic seeding* technique, i.e. artificially creating ice freezing nuclei and generating ice crystals in supercooled clouds and fogs. The ice crystals may grow faster than the water droplets owing to condensation of the atmospheric water vapor, since a supersaturation with respect to ice is higher than that with respect to liquid water. As a result of this grows, the large ice crystals (or water drop-collectors on such crystals) dispersed in the air may attain the sizes sufficient to collect other cloud droplets to trigger precipitation.

Glaciogenic seeding may be accomplished, for example, by vaporizing silver iodide at a high temperature and causing it to recrystallize, or by spraying into the atmosphere a solution of silver iodide in ammonia, or by burning a solution of silver iodide in acetone. Various methods of generating fine particles and multicomponent aerosols on the basis of glaciogenic seeding techniques for the precipitation of atmospheric water are disclosed, for example, in U.S. Pat. No. 3,429,507 to Jones; U.S. Pat. No. 3,613,992 to Knollenberg; U.S. Pat. No. 3,788,543 to Amand *et al*; U.S. Pat. No. 4,096005 to Slusher; U.S. Pat. No. 5,174,498 to Popovitz-Ronit *et al*; U.S. Pat. No. 5,360,162 to Mentus, and U.S. Pat. No. 6,056,203 to Fukuta.

One of the main drawbacks of the prior art glaciogenic seeding methods is their limited operability, since they may be utilized only when cloud or fog water droplets are below the freezing point of water (around 0 ^{0}C).

Various techniques for promoting the precipitation of cloud and fog droplets at temperatures above the freezing point of water are also known in the art. These techniques are based on dispersing the particles having the property of absorbing the water from clouds and fog, thereby creating large droplet-collectors.

One such technique for triggering raindrop formation through the acceleration of large droplets formation is the *hygroscopic seeding* technique. This technique is widely utilized for rain enhancement and fog dispersal (see, for example, G.B. Pat. No 1,110,768; U.S. Pat. No. 3,378,201 to Glew *et al*; U.S. Pat. No. 3,608,810 to Kooser; U.S. Pat. No. 3,608,820 to Kooser; U.S. Pat. No. 3,659,785 to Nelson; U.S. Pat. No. 3,802,624 to Kuhne; U.S. Pat. No. 3,896,993 to Serpolay; U.S. Pat. No. 3,940,059 to Clark; U.S. Pat. No. 4,362,271 to Montmory; U.S. Pat. No. 4,653,690 to St. Amand *et al.*; and U.S. Pat. No. 5,357,865 to Mather).

The prior art hygroscopic seeding techniques suffer from numerous drawbacks. For example, when granular materials are used as seed agents, their hygroscopic nature often causes agglomeration and caking in storage, even in the

presence of low moisture content. These negative phenomena lead to the creation of particles of sizes which are usually much greater than the desired value, that is, e.g., about 1 to 10 microns in radius. Notwithstanding that huge hygroscopic particles could be appropriate for the creation of large drop-collectors, such particles are rather heavy for transportation by airplanes to provide the desirable concentration of such particles into clouds. Thus, the utilization of such materials turns out to be inefficient.

Another example of hygroscopic materials widely used for cloud seeding is particles obtained by burning (flares). However, these materials contain mainly small particles (less than 1 micron in radius), leading to the growth of small droplets, which are ineffective for precipitation. In other words, the fraction of the large particles (effective for the purpose of creating drop-collectors) in the flares is remarkably lower than that of the small particles. Since the effects of the small and large particles on the drop growth are opposite, the total effect of the seeding is not clear (see, for example, R.T. Bruintjes, "*A review of cloud seeding experiments to enhance precipitation and some new prospects*", *Bull. Amer. Met. Soc.*, 1999, V. 80, P. 805-819).

Also known in the art are *electrostatic precipitation* techniques employing an electrical field to force liquid particles in the fog together to form large drops of sufficient mass to precipitate. For example, U.S. Pat. No. 3,600,653 to Hall describes a method for reducing fog density by passing the fog between a pair of electrodes. However, this method may be utilized only with equipment emitting artificial fog, since the installation of electrodes above a runway for water precipitation in natural fogs would be highly impractical.

U.S. Pat. No. 4,475,927 to Loos describes a technique for the abatement of fog in a space over an aircraft approach zone and runway. According to this technique, charged droplets of both polarities are introduced in the space by air jets. These positively charged droplets having sufficiently low mobility in order to stay long enough are blown aloft to form a virtual electrode suspended at an appropriate height above the ground. The negatively charged droplets (collector

drops) are given high enough mobility for collecting of fog drops in an upward motion in the electric field created between the spaced-apart positively and negatively charged droplets.

U.S. Pat. No. 4,671,805 to Gourdine describes an EGD (electro-gas-dynamic) system deployed in an array and used for the precipitation of fog over airports. The patent discloses a technique for producing a cloud of sub-micron size charged water droplets that are sprayed into the atmosphere for creating a space-charge cloud above a runway extending to a height of a few tens of meters. The cloud has a maximum electric field strength at the ground, and a zero field strength at the top of the cloud. The charged water droplets, in their earthward motion under the electric force, attach themselves to any other particles that may be suspended in the space-charge cloud. Precipitation occurs also as wind transports the spaced-charge cloud.

It should also be mentioned that U.S. Pat. No. 4,671,805 observes that seeding fog with electrically charged particles from an airplane was contemplated but discarded in favor a ground-based system owing to the many operational difficulties of an airborne system. The patent does not expand on the nature of these operational difficulties, but in any event, is restricted to a discussion of ground based systems for fog precipitation principally for dispersing fogs near airports and the like. Moreover, no suggestion is made as to how this can be achieved controllably.

One of the main drawbacks of the electrostatic precipitation prior art techniques is their inefficiency, since these techniques require high energy consumption for producing an electromagnetic field over a large space or territory. Therefore, these techniques cannot be utilized over large areas of fog and clouds.

U.S. Pat. No. 4,684,063 to Goudy, Jr. describes a mixer/charger apparatus for a variety of purposes employed simultaneously to mix and to electrically charge a fluid flowing therethrough. In one version, the mixer/charger apparatus includes a liquid supply from which the charged mist ultimately is produced for

seeding clouds. In an alternate version, the apparatus employs an air input supply that is delivered to a mixer/charger that produces a charged air output used to effect seeding function.

The techniques mentioned above are addressed to seeding clouds and fog for rain enhancement and/or fog abatement. However, as mentioned above, uncontrolled seeding may result in phenomena that are opposite from what the users expected. For example, the utilization of many conventional glaciogenic and hygroscopic techniques may result in the production of small droplets that are ineffective for rain formation.

Thus, despite the extensive prior art in the area of treating atmospheric conditions by seeding various materials, there is still a need for further improvements for controlling the precipitation of atmospheric water.

SUMMARY OF THE INVENTION

The present invention satisfies the aforementioned need by providing a novel method of controlling atmospheric conditions in a portion of the atmosphere for weather modification. The portion of the atmosphere may, for example, be a portion of a cloud or fog containing water droplets having different sizes dispersed therein. The droplet size is usually distributed in a broad spectrum of sizes.

The control of atmospheric conditions is carried out by controllably urging the collisions between the water droplets in the atmosphere so as to cause their controllable coalescence. The urging is characterized by adjusting non-gravitational attraction forces between the droplets to a predetermined value so as to alter a collision rate between the water droplets to a desired value.

The changes of the non-gravitational attraction forces between the droplets are achieved by dosed seeding in a portion of a cloud or fog a particulate material that is electrically charged to a required magnitude and polarity. The dosed seeding of the charged materials controls the concentration of the charged

droplets and the electric attraction between the charged droplets with neutral droplets as well as the electric interaction between the charged droplets.

The droplets in natural clouds and fogs are usually electrically neutral and represent weak salt solutions. The particulate charged material utilized for seeding contains charged fine particles that may be obtained, for example, by passing a particulate material through an electric discharge (e.g., a corona discharge).

When the charged particles approach an electrically neutral droplet at a distance sufficient for electrical interaction, a charge with a polarity opposite to the charge of the particle is induced on the side of the droplet facing the particle. The induced charge causes an electrical attraction between the particle and droplet, i.e. a non-gravitational attraction. This attraction results in a close approach and capture of the charged particle by the droplet. The droplet that received the charge from the charged particle can, in its turn, attract another electrically neutral droplet with a consequent approach and coalescence that would not be possible in the case of a pure gravity-induced attraction. The attractions increase the collision efficiency between the droplets and the rate of their collisions, which in turn fosters the formation of large droplets leading to raindrops in clouds. In case of fog, it leads to the elimination of small droplets owing to their collisions and coalescence that results in fog dissipation.

The foregoing need is also accomplished by providing an apparatus for controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets. The apparatus includes a chamber for providing a particle flow stream, a charger coupled to the chamber for charging the particles in the particle flow stream, a seeder for controllably scattering the charged particles in the atmosphere and a control module for controlling the operation of the apparatus.

The chamber of the apparatus includes a feeder for allowing the introduction of raw material into the chamber, a mixer for mixing an air flow stream with a particulate material derived from the raw material and an outlet for releasing an output obtained thereby to the charger.

According to one non-limiting example, the air flow stream is provided by a fan coupled to he chamber. According to another non-limiting example, the air flow stream is provided by an inlet arranged in the mixer. The inlet is fitted for receiving an input air flow stream and transferring this stream to the chamber thereby providing the air flow stream.

In order to control the operation of the apparatus, the control module of the apparatus is equipped with conventional devices for indicating and controlling certain parameters such as the amount and kind of raw material to be used, the strain of the air in the air flow stream, the strain of the particle flow stream, the strain of the charged particle flow stream, the size, charge and concentration of the particles in the particle flow stream, etc.

Accordingly, the control module of the apparatus can include a first strain regulator arranged in the inlet for producing a first sensor signal representative of the strain of the air in the air flow stream. The control module is responsive to the first sensor signal for controlling the strain. The control module can also include a second strain regulator arranged in the outlet for producing a second sensor signal representative of the strain of the particle flow stream. The control module is responsive to the second sensor signal for controlling the strain. Further, the module can also include a third strain regulator arranged in the seeder for producing a third sensor signal representative of the strain of the charged particle flow stream. The control module is responsive to the third sensor signal for controlling the strain.

The control module can include a charge regulator arranged in the charger and is responsive to a signal produced thereby for controlling the charge magnitude and/or polarity of the charged particles.

The apparatus receives electric power from an electrical power source and can also include a burner coupled to the chamber for burning the raw material so as to form the particulate material as a combustion product. In such a case, the control module preferably includes a temperature regulator arranged in the chamber. The

temperature regulator is responsive to a signal produced thereby for controlling the temperature in the burner.

The technique of the present invention for controlling the atmospheric conditions has many of the advantages of the aforementioned prior art techniques, while simultaneously overcoming some of the disadvantages normally associated therewith.

Despite the large variety of the prior art techniques dealing with seeding clouds and fog with glaciogenic and hygroscopic materials and also with charged droplets, none of the techniques addresses the controllable seeding of charged particulate materials.

As far as the conventional glaciogenic and hygroscopic seeding techniques are concerned, it is relevant to note that the method of the present invention can provide a significantly higher collision efficiency than the conventional methods used for seeding particulate materials, which lack the step of charging the particles.

Since the electric force is usually larger than the force of hydrodynamic attraction of droplets due to gravity, the charging of particulate seed materials can even provide collisions and precipitation of small droplets, having sizes of 1-10 microns in radius, that is impossible in the glaciogenic and hygroscopic seeding techniques. Thus, in contrast to these techniques, not only particles having a size higher than 1 micron can serve as a seed agent, but even rather small particles of about 0.1 to 1 micron do so. In this case, the competing effects of small and large particles, that crucially decrease the efficiency of the prior art methods of glaciogenic and hygroscopic seeding, are eliminated, and both small and large charged particles can accelerate the process of large drop formation.

Additionally, according to the invention, the raw particulate material utilized for producing charged particles can be selected from a very broad type of conventional materials. Therefore, many inexpensive and easily produced materials (e.g., soot) may be utilized.

Thus, according to one broad aspect of the present invention, there is provided a method of controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets dispersed therein, the method comprising the step of controllably altering an effective collision rate between the water droplets so as to produce their desired coalescence and precipitation.

According to another broad aspect of the present invention, there is provided an apparatus for controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets dispersed therein, the apparatus comprising:

(a) a chamber for providing a particle flow stream containing particles having a predetermined size, the chamber comprising:
   (i) a feeder for allowing introduction of raw material of a required kind in a required amount,
   (ii) a mixer for mixing an air flow stream with a predetermined amount of particulate material derived from said raw material, thereby producing said particle flow stream,
   (iii) an outlet for releasing said particle flow stream;

(b) a charger downstream of the chamber and in communication therewith via the outlet for charging the particles in said particle flow stream so as to produce charged particles having a predetermined polarity and charge magnitude;

(c) a seeder for controllable scattering said charged particles in said portion of the atmosphere;

(d) a control module for controlling operation of the apparatus, and

(e) an electrical power source for providing electrical power required for operation of the apparatus.

There has thus been outlined, rather broadly, the more important features of the invention in order that the detailed description thereof that follows hereinafter may be better understood. Additional details and advantages of the

invention will be set forth in the detailed description, and in part will be appreciated from the description, or may be learned by practice of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

Fig. 1 illustrates a scheme of collisions of small droplets with a large drop (a drop-collector);

Fig. 2 illustrates an example of the dependence of the collision efficiency on the ratio between the small uncharged droplet and the uncharged drop-collector of Fig. 1, shown for various radii of the drop-collector.

Fig. 3 illustrates an example of the dependence of an electric attraction force between a typical droplet and a typical charged particle on the distance therebetween.

Fig. 4 illustrates three examples of the dependence of the collision efficiency on the droplet charge for cloud.

Fig. 5 illustrates two examples of the dependence of the collision efficiency on the droplet charge for fog.

Fig. 6 is a schematic block diagram of an apparatus according to one embodiment of the present invention.

DETAILED DESCRIPTION OF SPECIFIC EMBODIMENTS

The principles and operation of a method and an apparatus according to the present invention may be better understood with reference to the drawings and the accompanying description, it being understood that these drawings are given for illustrative purposes only and are not meant to be limiting.

The present invention provides a novel method and apparatus for controlling atmospheric conditions in a portion of the atmosphere for weather

modification. The portion of the atmosphere may, for example, be a portion of a cloud or fog containing water droplets having different sizes dispersed therein.

The control of atmospheric conditions is carried out by controllably urging the collisions between the water droplets in the atmosphere so as to cause their controllable coalescence. The urging is characterized by adjusting non-gravitational attraction forces between the droplets to a predetermined value so as to alter a collision rate between the water droplets to a desired value.

The collision rate is proportional to the collision efficiency and to the droplet concentration according to Eq. (4). Therefore, altering the non-gravitational attraction forces between the droplets can result in altering the effective collision rate, thereby causing the enhancement or reduction of coalescence and precipitation of the droplets in their motion under the force of gravity.

The changes of the non-gravitational attraction forces between the droplets are achieved by dosed seeding in a portion of a cloud or fog of a particulate material that is electrically charged to a required magnitude and polarity. The particulate charged material utilized for seeding contains charged fine particles that may be obtained, for example, by passing a particulate material through an electric discharge (e.g., a corona discharge). The dosed seeding of the charged materials controls the concentration of the charged droplets and the electric attraction between the charged droplets with neutral droplets as well as the electrical interaction between the charged droplets.

The droplets in natural clouds and fogs are usually electrically neutral and represent weak salt solutions. Upon the approach of a charged particle of the charged particulate material to an electrically neutral droplet at a distance sufficient for electrical interaction, a charge with a polarity opposite to the charge of the particle is induced on the side of the droplet that is facing the particle. This induced charge causes a non-gravitational attraction, such as an electrical attraction between the particle and droplet. The magnitude of the attraction force in air can, for example, be derived from the following equation (see, for example,

B.I. Bleaney and B. Bleaney, Electricity and Magnetism, Oxford University Press, Third Edition, 1976, v. 1, p. 58):

$$F = \frac{q^2}{4\pi\varepsilon_0}\left[\frac{Ra}{\left(a^2 - R^2\right)^2} - \frac{R}{a^3}\right] \qquad (a > R)\,, \qquad (5)$$

where R is the radius of the neutral droplet, a is the distance between the centers of the charged particle and the droplet, q is the particle charge and $\varepsilon_0 = 8.854\ 10^{-12}$ F/m is the universal dielectric constant.

Fig. 3 illustrates the dependence of the electric attraction force between a droplet and a charged particle (calculated by using Eq. (5)) on the distance between the droplet and particle. For this example, magnitudes of the particle charge and the droplet radius were set to $q = 10^{-17}$ C and $R = 10$ microns, respectively.

This attraction results in a close approach and capture of the charged particle by the droplet. The droplet that received the charge from the charged particle can, in its turn, attract another electrically neutral droplet with consequent approach and coalescence that would not be possible in the case of pure gravity-induced attraction. These attractions increase the collision efficiency between the droplets and the rate of their collisions, which in turn foster the formation of large droplets leading to raindrops in clouds. In case of fog, it leads to the elimination of small droplets due to their collisions and coalescence that results in fog dissipation.

In order to understand the manner in which the collision efficiency between the droplets depends on the sizes and electrical charges of the droplets (particles) and to see how the collision efficiency can be altered to a desired value in practice by varying these parameters, several non-limiting examples of computer simulations are described hereinafter in details.

In general, for the purpose of the invention, the particles of the particular materials utilized for seeding may have a spread of sizes ranging from sub-micron to several microns size, e.g., between 0.1 and 20 microns. The charge may have

negative or positive polarity, and magnitude of the charged particles may, e.g., range from -10^{-15} Coulomb to $+10^{-15}$ Coulomb.

The collision efficiency can be calculated by utilizing Eq. (3). Turning to Fig. 1, an example of the case of axisymmetric geometry of the collisions is illustrated. In this example, the collision cross section **17** is a circle having a center **18** located on a vertical axis **19** passing through a center **10** of the large drop **12**.

A calculation of a radius of the collision cross section **17** can be carried out by numerical simulation experiments of the approach of the small droplets **11** to the large drop **12**. For the purpose of the numerical experiments, various state-of the-art mathematical models can be used for a hydrodynamic description of the droplet motions. For example, a superposition method can be considered, according to which each droplet is assumed to move under the gravitational, electric, buoyancy and drag forces in the flow induced by its counterpart moving alone. This method is described in the following publications:

M. Pinsky, A. Khain, and M. Shapiro, "*Collisions of small drops in a turbulent flow. Pt.1 : Collision efficiency: problem formulation and preliminary results*," *J. Atmos. Sci.*, 1999, v. 56, p. 2585-2600; and

M. Pinsky, A. Khain, and M. Shapiro, "*Collision efficiencies of drops in a wide range of Reynolds numbers: Effects of pressure*," *J. Atmos. Sci.,* 2001, v. 58, p. 742-764.

At the beginning of the simulation, a mutual motion of the large drop **12** relative to one small droplet (e.g., a droplet **111** in Fig. 1) that is selected from the droplets **11** can be carried out. The small droplet **111** is selected subject to the condition that it is located on the axis **19** below the large drop **12** at a distance of larger than $30R$ (i.e., 30 radii of the large drop) from the large drop **12**. The distance is selected subject to the condition that at the start of the simulation, the electric and hydrodynamic interactions between the drop **12** and the droplet **111** should be insignificant. During motion under gravity, the large droplet moves faster than the small droplet owing to the counteracting electrical, buoyancy and drag forces and

attains the distance at which the interactions start to affect the droplet relative motion that results in their collision.

In the next step of the simulation experiment, a hydrodynamic motion of another selected small droplet (for example a droplet **112)** relative to the large drop **12** can be considered. The droplet **112** can also be placed at the distance of $30R$ from the large drop **12.** However, the initial distance of small droplet **112** from the vertical axis **19** should be successively increased.

Thereafter, the simulation experiment can be continued with a consequent increase of the initial distance of the small droplet from the vertical axis **19**. In each of these simulations, trajectories of the approach of the small droplets to the drop collector and variations in time of the distances between the small droplets and the large drop can be calculated.

It should be appreciated that the collisions between the small droplets and the large drop may take place only when the initial deviations of the small droplets from the vertical axis are relatively small. On the other hand, when the initial deviations start to exceed a certain value, the small droplets will move around the large droplet together with the airflow without collisions. This distance (deviation) separating a zone of collisions from the non-collision zone can be defined as a radius of the collision cross-section **17**.

For example, the large drop **12** can be considered to be electrically neutral and the small droplets **11** to be electrically charged. In this case, in order to adjust the collision efficiency to a desired value the simulations can be run for various sizes of the large drop as well as various sizes and charge of the small droplets.

It should be understood that a collision efficiency between the droplets and particles, when necessary, can be calculated in the same manner as the collision efficiency between the drops and droplets.

Referring now to Fig. 4, three examples of calculations of the collision efficiency between the drop-collector and droplets (particles) as a function of the droplet (particle) charge are illustrated. In these examples, the size of the drop-collector is 10 microns in radius and the sizes of the small droplets

(particles) are 1 micron (curve **41**), 2 microns (curve **42**) and 5 microns (curve **43**), respectively. This situation of the droplet sizes is typical for cumulus clouds. However, it should be noted that if a droplet radius in fog have a magnitude of up to 10 microns, then Fig. 4 serves also as illustration for the fog conditions.

It can be seen that in the absence of electrical attraction between the droplets (i.e., when the drop and droplets are not charged), the collision efficiency has a magnitude of about 0.003, 0.01 and 0.02 for the droplets having the size of 1 micron, 2 microns and 5 microns, respectively. This means that the drop and droplets, in fact, do not collide over a reasonable period of time.

However, the situation changes when the droplets are charged. In this case, the collision efficiency between the drop-collector and the 5 micron droplet increases by about 10 times, when the droplet receives a charge having a value of about 2 10^{-16} Coulomb (see curve **43**).

The collision efficiency increases even more drastically for the droplets having radii of 1 micron and 2 microns. Thus, the collision efficiency increases by about two orders of magnitude for the droplets having a radius of 2 microns (see curve **43**) and by about three orders of magnitude for the droplets having a radius of 1 micron (see curve **43**).

It can be noted that the magnitude of the collision efficiency for certain situations can exceed 1 (see curve **41**). In other words, the collision cross section (**17** in Fig. 1) is larger than the geometrical cross-section (**14** in Fig. 1), meaning that even the droplets located outside the volume of the cylinder (**13** in Fig. 1) participate in the collisions. In general, by utilizing the technique of the invention, the collision efficiency may be varied in a rather broad range, for example, from 0.001 to 100.

It should be appreciated that in contrast to the teaching of the prior art, the computer experiment shows that collision efficiency for the smaller droplets (particles) is higher than the collision efficiency for the larger droplets (particles). This unexpected result provides an advantage of the method of the present invention that was unappreciated hitherto. As was mentioned above, one of the

major requirements of the prior art techniques was producing large seed particles, since the small particles are not effective for creating large drop-collectors. In particular, the techniques based on seeding combustion products obtained by burning are not sufficiently effective since the combustion product contain mainly small particles. Thus, the main drawback of the prior art technique that militates against the use of small seed particles is overcome by the invention and actually used to advantage.

Fig. 5 illustrates examples of calculations of the collision efficiency for a situation relevant to fogs. The collision efficiency is calculated as a function of the droplet (particle) charge for the drop-collectors having radius of 2 microns (see curve **51**) and 3 microns (see curve **52**) interacting with the small droplets (particles) having the radius of 1 micron. In the case when the droplets are uncharged the collision efficiency is about 10^{-2}. However, the collision efficiency between the neutral and charged droplets increases by 2 to 3 orders of magnitude, depending on the charge value.

Referring now to Fig 6, there is illustrated a schematic block diagram of an apparatus **60** for controlling atmospheric conditions in a portion **66** of the atmosphere, according to one embodiment of the present invention. It should be noted that the blocks in Fig. 6 are intended as functional entities only, such that the functional relationships between the entities are shown, rather than any physical connections and/or physical relationships.

The apparatus **60** includes a chamber **61** for providing a particle flow stream **63**, a charger **62** coupled to the chamber for charging the particles **64** in the particle flow stream **63**, a seeder **65** for releasing a charged particle flow stream **70** and controllably scattering charged particles **71** of the charged particle flow stream **70** in the portion **66** of the atmosphere, and a control module **67** for controlling the operation of the apparatus **60**.

The chamber **61** of the apparatus includes a feeder **610** for allowing the introduction of raw material (not shown) into the chamber **61**, a mixer **620** for mixing an air flow stream **68** with a particulate material derived from the raw

material and an outlet **72** for releasing an output obtained thereby to the charger **62**.

The air flow stream **68** may be provided with a fan (not shown) coupled to the chamber **61**. According to another non-limiting example, the air flow stream **68** is provided by an inlet **621** arranged in the mixer **620**. The inlet **621** is fitted for receiving an input air flow stream **69** and transferring this stream to the chamber **61** via the mixer **620**, thereby providing the air flow stream **68**.

In order to control the operation of the apparatus, the control module **67** of the apparatus **60** is equipped with various conventional devices for indicating and regulating certain parameters such as the amount and kind of the raw material to be used, the strain of the air in the air flow stream **68**, the strain of the particle flow stream **63**, the strain of the charged particle flow stream **70**, the size, charge and concentration of the particles **71** in the particle flow stream **70**, etc.

Accordingly, the control module of the apparatus can include a first strain regulator **81** arranged in the mixer **620** for producing a first sensor signal representative of the strain of the air in the air flow stream **68**. The control module **67** is responsive to the first sensor signal for controlling the strain. The control module **67** can also include a second strain regulator **82** arranged in the outlet **72** for producing a second sensor signal representative of the strain of the particle flow stream. The control module is responsive to the second sensor signal for controlling the strain. Further, the module can also include a third strain regulator **83** arranged in the seeder **65** for producing a third sensor signal representative of the strain of the charged particle flow stream **70**. The control module **67** is responsive to the third sensor signal for controlling the strain.

The control module **67** can include a charge regulator **84** coupled to the charger **62**. The regulator is responsive to a signal produced thereby for controlling the charge magnitude and/or polarity of the charged particles.

The apparatus **60** can also include a burner **630** coupled to the chamber **61** for burning the raw material so as to form the particulate material as a combustion

product. In such a case, the control module **67** preferably includes a temperature regulator **84** coupled to the burner **630**. The temperature regulator is responsive to a signal produced thereby for controlling the temperature in the burner.

The apparatus receives electric power from an electrical power source **80** coupled to the chamber **61**, charger **62**, seeder **65** and their components for providing electrical power for operation of the apparatus.

According to one embodiment of the invention, controlling the atmospheric conditions for the purpose of rain regulation by seeding electrically charged particles in clouds can be carried out by the apparatus that is mounted on a flying object, e.g., an airplane, helicopter or dirigible. For the controllable dispersal of fog or ground mist, the apparatus can be carried on a motorized vehicle. Likewise, the water droplets of fog can be treated by a low flying airplane controllably dispersing the electrically charged particles in accordance with the invention.

According to another embodiment of the invention, the control of the atmospheric conditions can be effected from a ground located source, e.g. from a chimney-stack. In this case, the charger, of the kind described above, can be mounted within the chimney-stack in order to charge the smoke particles ejected into the atmosphere when clouds or fog are in the vicinity of the chimney-stack. The controllable scattering of the charged smoke particles not only affects the atmospheric conditions, but can also scavenge the atmosphere from the ejected materials.

Use of the method and apparatus according to the invention may result in a higher precipitation of rain than hitherto-proposed techniques and rain produced using the method and apparatus according to the invention falls within the scope of the invention as defined by the appended claims.

As such, those skilled in the art to which the present invention pertains, can appreciate that while the present invention has been described in terms of preferred embodiments, the concept upon which this disclosure is based may

readily be utilized as a basis for the designing of other structures, systems and processes for carrying out the several purposes of the present invention.

It is apparent that although the examples based on the numerical experiments were shown for interaction between the neutral drop and electrically charged droplets (particles), the method of the present invention can be applied for controlling the collision rate between the charged drops and neutral droplets (particles), or charged drops and charged droplets (particles).

Moreover, any reference to a specific implementation in terms of usage of the chamber, the charger, the control module, or any other components are shown by way of a non-limiting example.

Also, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

It is important, therefore, that the scope of the invention is not construed as being limited by the illustrative embodiments set forth herein. Other variations are possible within the scope of the present invention as defined in the appended claims and their equivalents.

CLAIMS:

1. A method of controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets dispersed therein, the method comprising controllably altering an effective collision rate between the water droplets so as to produce their desired coalescence and precipitation.

2. The method of claim 1 wherein said portion of the atmosphere is a portion of cloud.

3. The method of claim 1 wherein said portion of the atmosphere is a portion of fog.

4. The method of claim 1 wherein said droplets are substantially electrically neutral.

5. The method of claim 1 wherein said droplets are electrically charged.

6. The method of claim 1 wherein controllably altering an effective collision rate includes:

(a) providing a predetermined amount of a particulate material having particles of a predetermined size;

(b) electrically charging the particles so as to produce charged particles having a predetermined polarity and charge magnitude, said magnitude being sufficient at least for attraction between the charged particles and said microscopic water droplets; and

(c) seeding said charged particles in said portion of the atmosphere.

7. The method of claim 5 wherein providing a particulate material includes burning a pyrotechnic material.

8. The method of claim 7 wherein the particles are soot particles.

9. The method of claim 5 wherein the particulate material is a powdered solid material.

10. The method of claim 5 wherein the particles have a spread of sizes ranging from sub-micron to several micron sizes.

11. The method of claim 10 wherein the particle size ranges from 0.1 micron to 20 microns.

12. The method of claim 5 wherein the charge magnitude of the charged particles ranges from -10^{-15} Coulomb to $+10^{-15}$ Coulomb.

13. The method of claim 5 wherein electrically charging the particles comprising passing the particles through an electric discharge of a predetermined discharge characteristic.

14. The method of claim 13 wherein said electric discharge is corona discharge.

15. The method of claim 1 wherein said effective collision rate is proportional at least to a collision efficiency and a concentration of the droplets.

16. The method of claim 15 wherein said collision efficiency has a value higher than 1.

17. The method of claim 15 wherein said collision efficiency ranges from 0.001 to 100.

18. The method of claim 1 wherein the step of controlling atmospheric conditions is effected from a flying object.

19. The method of claim 1 wherein the step of controlling atmospheric conditions is effected from a ground located source.

20. The method of claim 19 wherein the ground located source is a chimney stack.

21. A method of controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets, the method comprising the step of:

urging collisions between said water droplets so as to cause their coalescence and precipitation,

characterized by:

adjusting non-gravitational attraction forces between the droplets to a predetermined value so as to alter a collision rate between the water droplets.

22. A method of claim 21 wherein said portion of the atmosphere is a portion of cloud.

23. A method of claim 21 wherein said portion of the atmosphere is a portion of fog.

24. A method of claim 21 wherein said droplets are substantially electrically neutral.

25. A method of claim 21 wherein the step of controlling non-gravitational attraction forces between said water droplets includes:

(a) providing a predetermined amount of a particulate material having particles of a predetermined size;

(b) electrically charging the particles so as to produce charged particles having a predetermined polarity and charge magnitude, said magnitude being sufficient at least for attraction between the charged particles and said microscopic water droplets; and

(c) seeding said charged particles in said portion of the atmosphere.

26. The method of claim 25 wherein providing a particulate material includes burning a pyrotechnic material.

27. The method of claim 26 wherein the particles are soot particles.

28. The method of claim 25 wherein the particulate material is a powdered solid material.

29. The method of claim 25 wherein the particles have a spread of sizes ranging from sub-micron to several micron sizes.

30. The method of claim 25 wherein the charge magnitude of the charged particles ranges from -10^{-15} Coulomb to $+10^{-15}$ Coulomb.

31. The method of claim 25 wherein electrically charging the particles comprising passing the particles through an electric discharge of a predetermined discharge characteristic.

32. The method of claim 31 wherein said electric discharge is corona discharge.

33. The method of claim 25 wherein said collision efficiency has a value higher than 1.

34. The method of claim 21 said effective collision rate is proportional at least to a collision efficiency and a concentration of the droplets.

35. The method of claim 34 wherein said collision efficiency has a value higher than 1.

36. The method of claim 34 wherein said collision efficiency ranges from 0.001 to 100.

37. The method of claim 21 wherein the step of treating atmospheric conditions is effected from a flying object.

38. The method of claim 21 wherein the step of treating atmospheric conditions is effected from a ground located source.

39. The method of claim 38 wherein the ground located source is a chimney stack.

40. An apparatus for controlling atmospheric conditions in a portion of the atmosphere containing microscopic water droplets dispersed therein, the apparatus comprising:

(f) a chamber for providing a particle flow stream containing particles having a predetermined size, the chamber comprising:

(i) a feeder for allowing introduction of raw material of a required kind in a required amount,

(iv) a mixer for mixing an air flow stream with a predetermined amount of particulate material derived from said raw material, thereby producing said particle flow stream,

(v) an outlet for releasing said particle flow stream;

(g) a charger downstream of the chamber and in communication therewith via the outlet for charging the particles in said particle flow stream so as to produce charged particles having a predetermined polarity and charge magnitude;

(h) a seeder for controllable scattering said charged particles in said portion of the atmosphere;

(i) a control module for controlling operation of the apparatus, and

(j) an electrical power source for providing electrical power required for operation of the apparatus.

41. The apparatus of claim 40, further comprising a burner coupled to the chamber for burning said raw material so as to form the particulate material as a combustion product.

42. The apparatus of claim 40 wherein said portion of the atmosphere is a portion of cloud.

43. The apparatus of claim 40 wherein said portion of the atmosphere is a portion of fog.

44. The apparatus of claim 40 wherein said droplets are substantially electrically neutral.

45. The apparatus of claim 40 wherein the particulate material is a powder.

46. The apparatus of claim 41 wherein said combustion product is soot particles.

47. The apparatus of claim 40 wherein the particles have a spread of sizes ranging from sub-micron to several micron sizes.

48. The apparatus of claim 40 wherein the value of the particles charge ranging from -10^{-15} Coulomb to $+10^{-15}$ Coulomb.

49. The apparatus of claim 40 wherein said mixer includes a fan for providing said air flow stream.

50. The apparatus of claim 40 wherein said mixer includes an inlet for receiving an input air flow stream and transferring the input air flow stream to the chamber thereby providing said air flow stream.

51. The apparatus of claim 40 wherein the charger comprises at least a pair of electrodes for producing an electric field.

52. The apparatus of claim 40 wherein the charger comprises at least a pair of electrodes for producing an electric discharge.

53. The apparatus of claim 40 wherein said control module includes a first strain regulator arranged in the inlet for producing a first sensor signal representative of a strain of the air in the air flow stream, the control module being responsive to said first sensor signal for controlling the strain.

54. The apparatus of claim 40 wherein said control module includes a second strain regulator arranged in the outlet for producing a second sensor signal representative of a strain of the particle flow stream, the control module being responsive to said second sensor signal for controlling the strain.

55. The apparatus of claim 40 wherein said control module includes a third strain regulator arranged in the seeder for producing a third sensor signal representative of a strain of the charged particle flow stream, the control module being responsive to said third sensor signal for controlling the strain.

56. The apparatus of claim 41 wherein said control module includes a temperature regulator arranged in the chamber and is responsive to a signal produced thereby for controlling temperature in the burner.

57. The apparatus of claim 41 wherein said control module includes a charge regulator arranged in the charger and is responsive to a signal produced thereby for controlling the charge magnitude and/or polarity of the charged particles.

58. The apparatus of claim 40 for use with a flying object.

59. The apparatus of claim 40 for use with a ground located source.

60. The apparatus of claim 40 wherein said ground located source is a chimney-stalk.

61. Rain produced by the method of claim 1.

For the Applicants,
REINHOLD COHN AND PARTNERS
By:

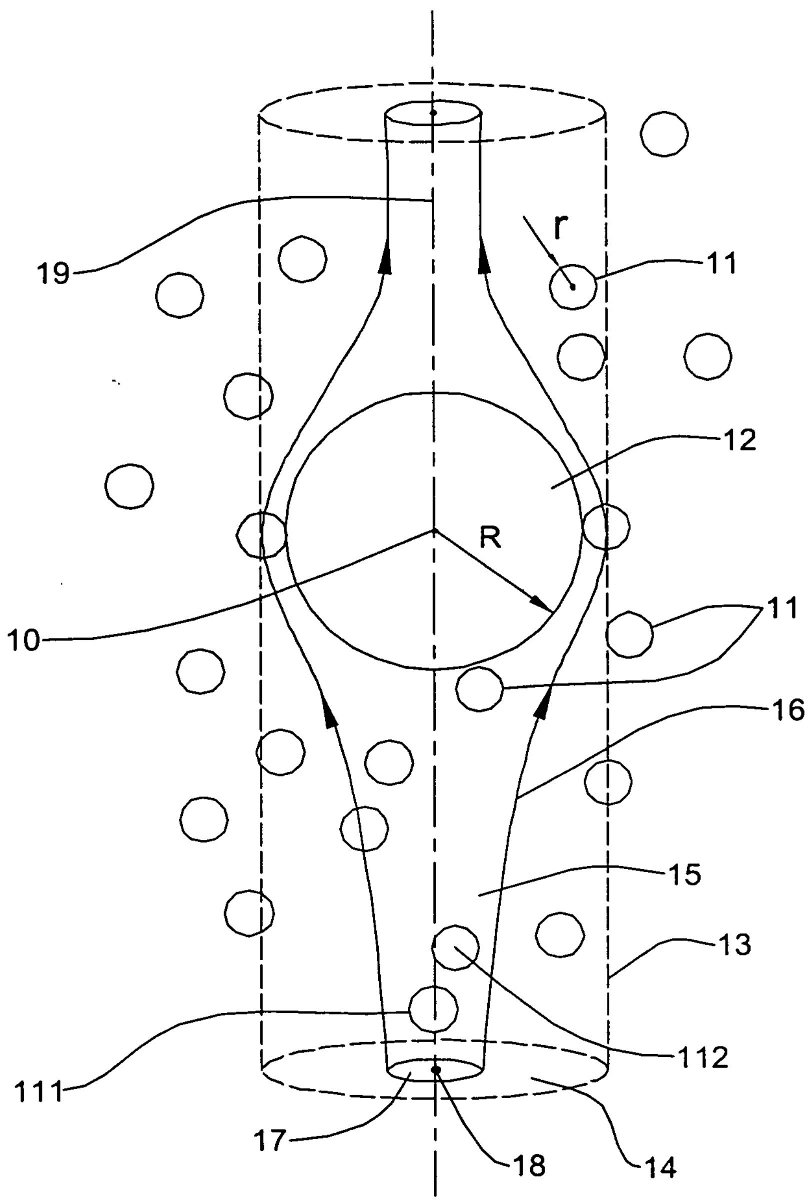


FIG. 1

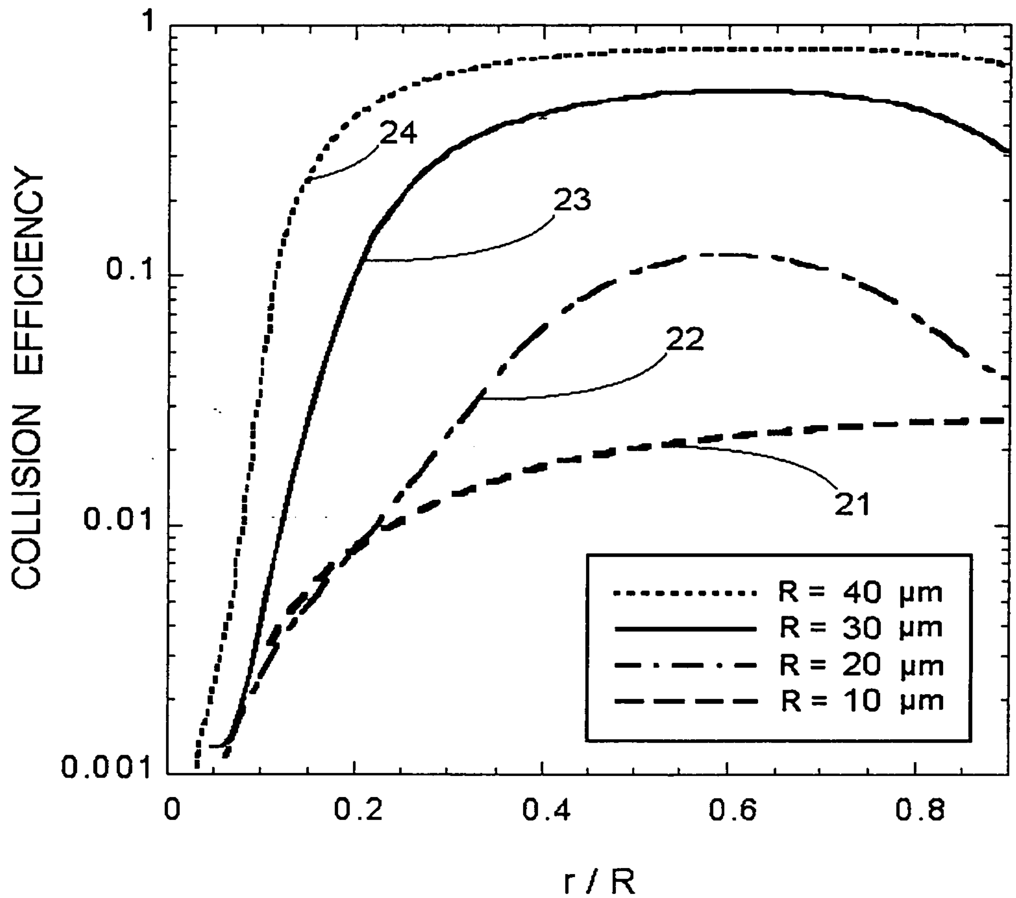
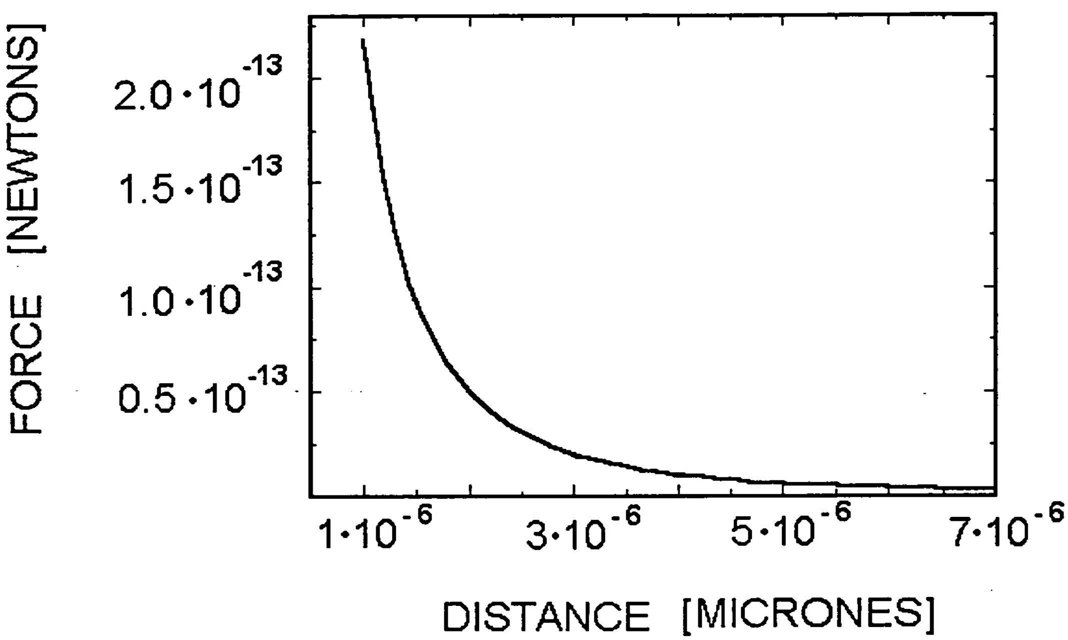

1
0.1
0.01
0.001
COLLISION EFFICIENCY
0
0.2
0.4
0.6
0.8
r / R
24
23
22
21
R = 40 µm
R = 30 µm
R = 20 µm
R = 10 µm

FIG. 2


FORCE [NEWTONS]
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1.5·10-13
1.0·10-13
0.5·10-13
1·10-6
3·10-6
5·10-6
7·10-6
DISTANCE [MICRONES]

FIG. 3

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6 Sheets
Sheet No. 4

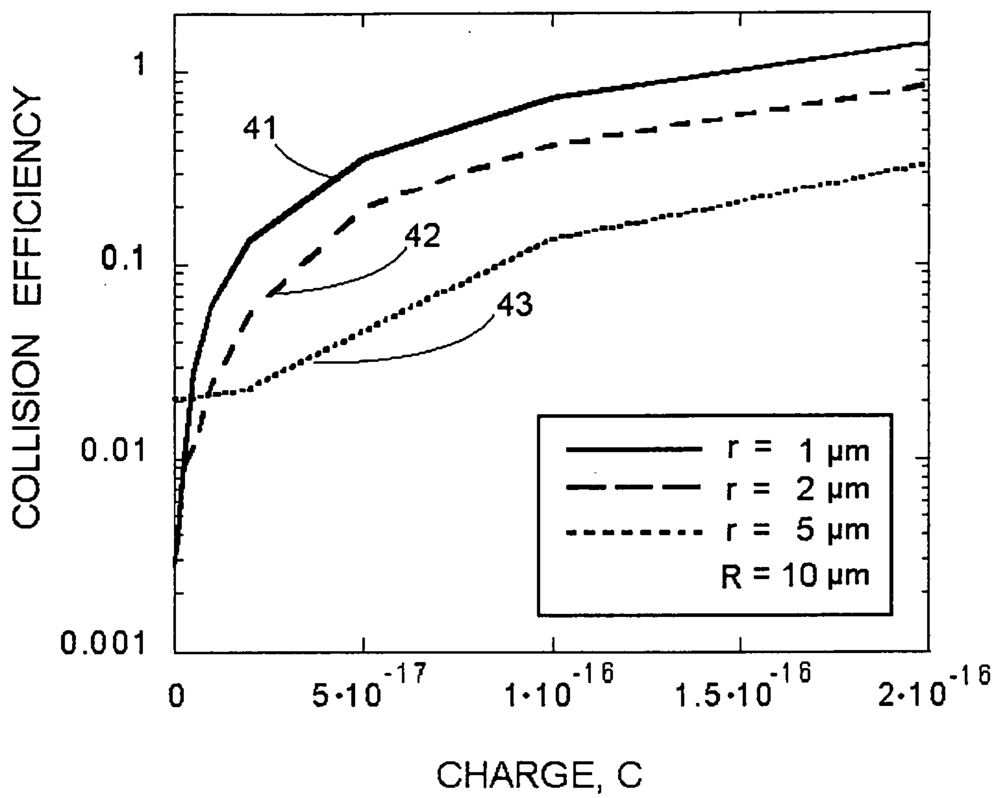

FIG. 4

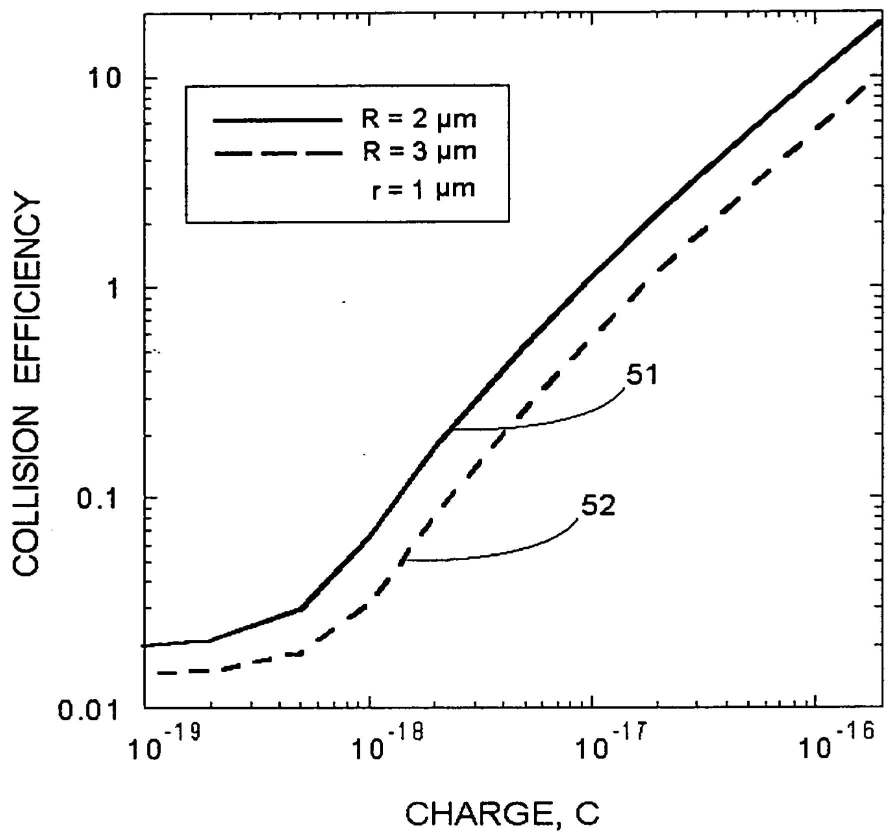
10
1
0.1
0.01
COLLISION EFFICIENCY
R = 2 μm
R = 3 μm
r = 1 μm
51
52
10^{-19}
10^{-18}
10^{-17}
10^{-16}
CHARGE, C

FIG. 5

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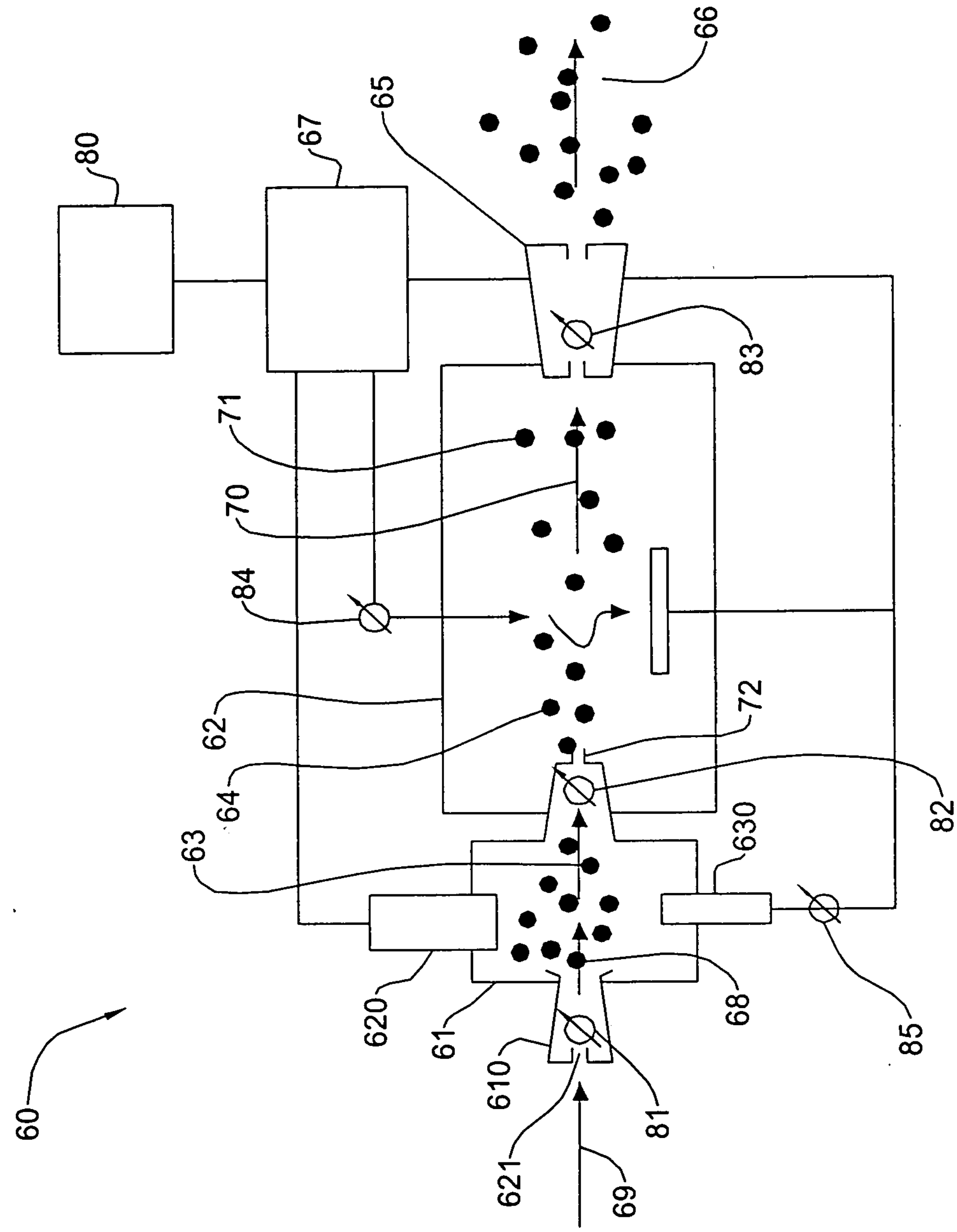

FIG. 6